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Image Edge Detection Based on Cellular Neural Network and Particle Swarm Optimization

Zhengxia Wang*[#]*, Lili Li

Department of Computer Science and Engineering, Chongqing Jiaotong University, Chongqing 400044, China

Email: zxiawang@163.com

Abstract

Edge detection is one of the basic pre-processing methods in digital image processing. In order to extract the edge of image effectively, this paper employs linear matrix inequality and particle swarm optimization (PSO) based on cellular neural networks (CNN). Among these templates obtained by using linear matrix inequality (LMI), we utilize the PSO to carry out the optimization parameters. The performance of the proposed edge detection method is evaluated on different test images and compared with popular methods from the reference. Simulation results indicate that the proposed method introduced in this paper offers superior performance in both binary and gray images edge detection.

Keywords: Cellular Neutral Network; Particle Swarm Optimization, Linear Matrix Inequality; Edge Detection

1. INTRODUCTION

Edge, one of the most basic features of an image, includes a series of important factors like direction, shape, step nature, etc. Therefore, edge detection is one of the most important and difficult steps in image processing, analysis and pattern recognition systems.

Image intensity shows abrupt changes at edges. So some typical edge detection operators are proposed by computing of local first or second derivative operate, such as Roberts, Prewitt, Sobel, LOG, Kirsh, etc. But several practices show that these typical operators are not ideal, and they can't meet people's demand for edge detection accuracy. Therefore, it is necessary to find some better methods to detect images edge.

In recent years, a few good methods in images edge detection have been proposed, such as mathematical morphology, wavelet transformation, differential evolution algorithm, contourlet probability distribution, neural networks [1] and so on. To some extent, they reduce the noise interference and improve the edge detection accuracy. Neutral network in image edge detection has become a useful research field, among which cellular neutral network [2,3] (CNN) is the representative of all.

The most important essential point of CNN application is to find a set of accurate templates. In recent years, much attention has been paid to the design methods of templates. Some good methods have been proposed like linear matrix inequality (LMI) method [4], adaptive threshold method [5], genetic algorithm method, differential evolution method [6] and particle swarm optimization (PSO) method [7], CPSO [10,11] and so on. They are used to find the correlation between the input and the desired output and the desired templates are obtained for edge detection.

In this paper, based on some research conclusions [4,7,8], we investigated the method of image edge detection by employing LMI, PSO and CNN. By solving a set of LMI, the original templates can be obtained by using the input image and corresponding output ideal edge image. Then PSO algorithm is used to get the optimal templates. And the obtained CNN templates are employed to extract edge from given images. Using this algorithm, we can get more precise image edge than only use LMI [4] or PSO [7].

The rest of this paper is organized as follows. Section 2 presents the models of PSO in brief. Section 3 presents the models of CNN in brief. Then, we propose a training method, using LMI and PSO, to produce the templates for image edge detection in section 4. In section 5, the performance of proposed method and other listed methods are compared for both binary and gray images. Finally, conclusions are given in section 6.

2. PARTICLE SWARM OPTIMIZATION (PSO)

PSO [9] was first proposed by James Kennedy and Russell Eberhart in 1995. The most attractive features are high optimization speed and effectiveness that can be use to find optimal solutions for numerical and qualitative problems.

First of all, the algorithm randomly initializes the position and velocity of a group of particles. Then, because of the particles' memory, each particle tries to modify its current position and velocity according to the distance between its current position and the *pbest*, and the distance between its current position and the *gbest*. Among which *pbest* is the best position each particle has experienced, and *gbest* is the best position the whole group has found. The loop doesn't stop until the criterion is met. Fig.1 shows the flowchart of the PSO algorithm.

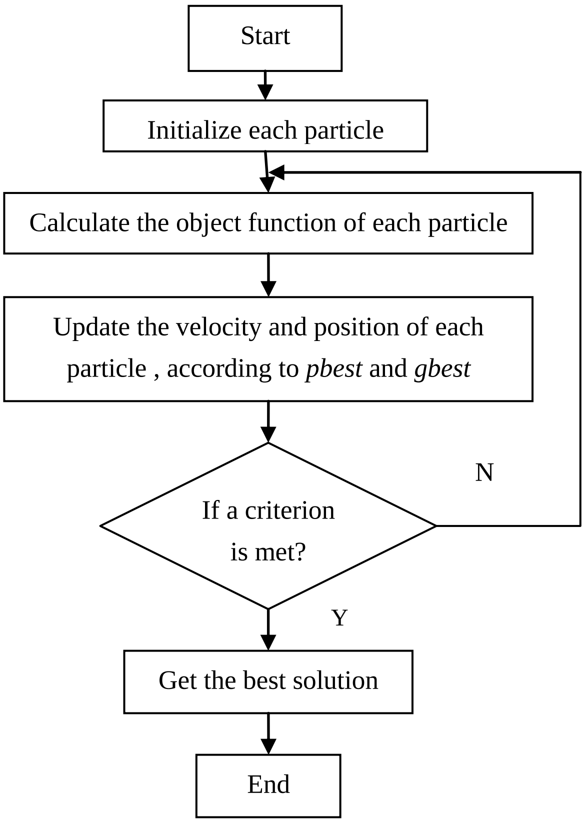

FIG.1 FLOWCHART OF PSO

In PSO, particle swarm scale as *N*, supposes that the search space is *d*-dimensional, and the *ith* particle is represented by $X_i = (x_{i1}, x_{i2}, \ldots x_{id})$, the velocity of this particle is represented by $V_i = (v_{i1}, v_{i2}, \ldots v_{id})$. The particles are manipulated according to the equations (1) and (2):

$$v_{id}(t+1) = w * v_{id}(t) + c_1 * rand()_1 * (p_{id} - x_{id}) + c_2 * rand()_2 * (p_{gd} - x_{id}). \tag{1}$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1). \tag{2}$$

where , $v_{ij}(t+1)$, $v_{ij}(t)$ represent particle i velocity at iteration $t+1$ and t, $x_{ij}(t+1)$, $x_{ij}(t)$ are particle i position at iteration $t+1$and t; c_1, $c_2$are acceleration coefficient related to *pbest* and *gbest*; w is inertia weight factor; $rand()_1$ and $rand()_2$ are random number uniform distribution $U(0,1)$;p_{id} is *pbest* position of particle i, $P_i = (p_{i1}, p_{i2}, \ldots p_{id})$; p_{gd} is *gbest* position of particle i , $P_g = (p_{g1}, p_{g2}, \ldots p_{gd})$.

3. CELLULAR NEURAL NETWORKS (CNN)

CNN [2,3] introduced by American famous scientists L.O.Chua and L.Yang in 1988 is a large-scale nonlinear artificial circuit that possesses real-time signal processing ability. In a standard $M\times N$ CNN, C_{ij} $(1\leq i\leq M)$denotes the cell located in *ith* row and *jth* column. The state equation and output equation of each cell could be expressed as below [2].

$$\dot{x}_{ij}(t) = -x_{ij}(t) + \sum_{c(k,l)\in N_r(i,j)} A(i,j;k,l)y_{kl}(t) + \sum_{c(k,l)\in N_r(i,j)} B(i,j;k,l)u_{kl}(t) + I. \tag{3}$$

$$y_{ij}(t) = f(x_{ij}(t)) = \frac{1}{2}(|x_{ij}(t)+1| - |x_{ij}(t)-1|) \tag{4}$$

where, $x_{ij}(t), u_{ij}$ and $y_{ij}(t)$ represent the status, input and output of the cell, $A(i,j;k,l)$ and $B(i,j;k,l)$ are feedback template and control template, the constraint condition $x_{ij}(0)=0$, $|u_{ij}|\leq 1$. The working principle of Eq.3 is depicted in Fig.2.

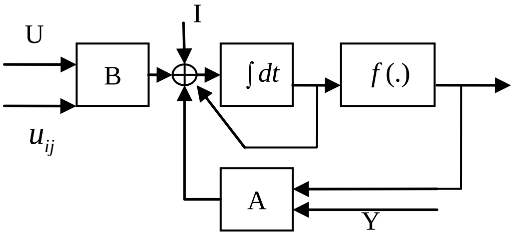

FIG. 2.SYSTEM STRUCTURE OF EQ.(3)

Each cell in CNN only connects to its neighborhood $N_r(i,j)$ (r stands for neighborhood radius, usually $r=1$) and interacted with each other directly, but the disconnected cells interacted with each other through continuous dynamic propagation effect. Cell neighborhood could be expressed as:

$$N_r(i,j) = \{c(k,l) = \max(|k-i|,|l-j|) \leq r, 1\leq k\leq M, 1\leq l\leq N\} \tag{4}$$

4. CNN TRAINING BY HYBRID LMI AND PSO

The most important factor of CNN applications is how to find the satisfactory templates, including threshold *I*, feedback template *A* and control template *B*. In literature [4], a LMI-based approach was proposed to extract image edge. But these resulting templates were just to meet the range of templates parameters, which weren't the optimal solution. In literature [8], authors combined the method of LMI and PSO approach was proposed to remove the noise from noise images and it got better results compared to only use LMI method. In this paper, in order to get the optimal templates, we utilize LMI and PSO to design CNN templates for images edge detection.

Specific steps are as follows.

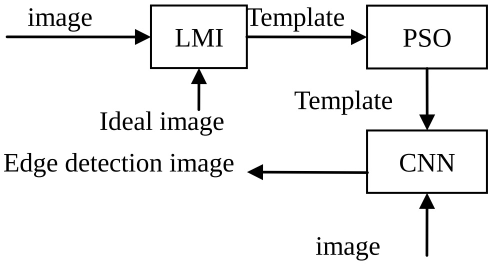

FIG.3. FLOW CHART OF IMAGE EDGE DETECTION

1) According to inequality equations and the system stable conditions, we can use LMI to get some templates that meet the constraints;

2) In order to get more accurate edge images, traditional PSO algorithm is used to find the optimal templates;

3) Using the optimal templates in CNN, edge of the image can be detected.

And the detail flow chart is shown in Fig.3.

CNN system stability is another main factor of CNN application. So before the analysis of our method, we must make sure that CNN system is stable.

Given CNN image edge detection templates

$$A=\begin{bmatrix}0&0&0\\0&a&0\\0&0&0\end{bmatrix},B=\begin{bmatrix}b_1&b_2&b_3\\b_4&b_5&b_6\\b_7&b_8&b_9\end{bmatrix},I=I_{ij}. \tag{5}$$

According to literature [4], we know if a>1 and initial condition $x_{ij}(0)=0$, then the final state will be stable, that is $|x_{ij}(\infty)|>1$.

In the following, we will give specific analysis of each step.

Image edge detection templates are trained by two images, one of which is input image u and the other is ideal image y. Then, we have the following results.

If $a>1$ and $x_{ij}(1)>0$, the following LMI are solvable [4]

$$\begin{cases} a+\sum\limits_{c(k,l)\in N_r(i,j)} B(i,j;k,l)u_{kl}+I>1, & y_i^*=1(x_{ij}^*\geq 1)\\ ay_i^*+\sum\limits_{c(k,l)\in N_r(i,j)} B(i,j;k,l)u_{kl}+I=y_i^*, & |y_i^*|<1(-1<x_{ij}^*<1)\\ a+\sum\limits_{c(k,l)\in N_r(i,j)} B(i,j;k,l)u_{kl}+I<-1, & y_i^*=-1(x_{ij}^*\leq -1) \end{cases} \tag{6}$$

From (7) and its prerequisites, we can obtain some templates that meet its constraints. Then we can use PSO algorithm to find the optimal templates. However, before this, we must set some necessary parameters (Table 1).

TABLE1. PSO Parameter Settings

Swarm size	12
Maximum position $X_{\max}$	1
Maximum velocity $V_{\max}$	10
Acceleration coefficient c_1	1.2
Acceleration coefficient c_2	1.2
Inertia weight ω	0.8
Iterations	200

After that, we should follow the steps in Fig.1.

1) Initialize the position, velocity and *pbest, gbest* of particles

2) Put *A*, *B* value into the formula (3) and (4), we can get y_{ij}, and its fitness formula $f(x)=\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{m}|\overline{y_{ij}}-y_{ij}|}$ can be obtained.

3) Compare the fitness value of each particle to its best position *pbest*, if the value is better then put this value as

the best position *pbest*. And the method of determining *gbest* is the same.

4) Update the particle velocity and position according to formula (1) and (2).

5) If it doesn't meet the loop termination condition, return to step (2).

Iteration termination conditions are generally divided into two sides: one is that iterations have reached its maximum, and the other is that the current best position the particle swarm searched has met the minimum fitness value.

Then, finding the optimal templates, the more accuracy edge can be detected by CNN.

5. SIMULATION AND ANALYSIS

In this section, some examples are presented to illustrate the effectiveness of the proposed method. Here we will use binary images and gray images to train the templates of CNN, respectively.

Firstly, the binary images training sample which consists of an image and its corresponding desired edge image, is used to train CNN templates. The proposed method is compared with the method of Reference [4].

Training templates in Fig.4 are as follows.

$$A=\begin{bmatrix}0 & 0 & 0\\ 0 & 6.5659 & 0\\ 0 & 0 & 0\end{bmatrix}\quad B=\begin{bmatrix}0 & -202.3456 & 0\\ -179.1754 & 743.2130 & 17\\ 0 & -202.3456 & 0\end{bmatrix}\quad I=267.33$$

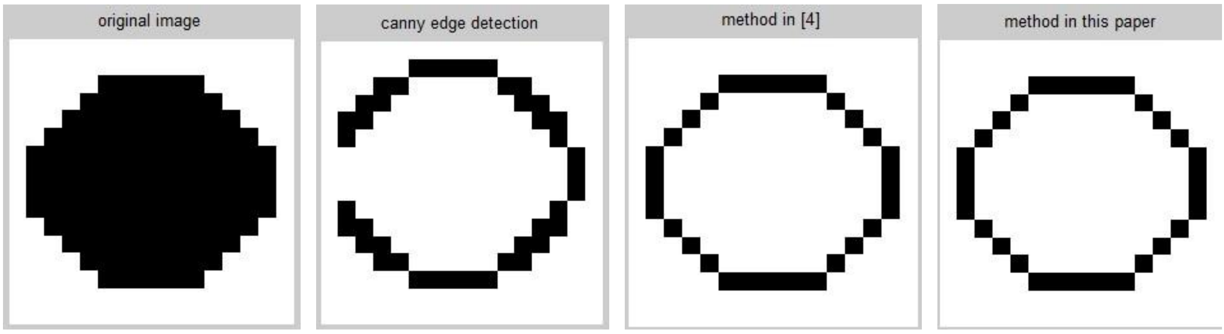

FIG.4. EDGE DETECTION OF HEXAGON IMAGE

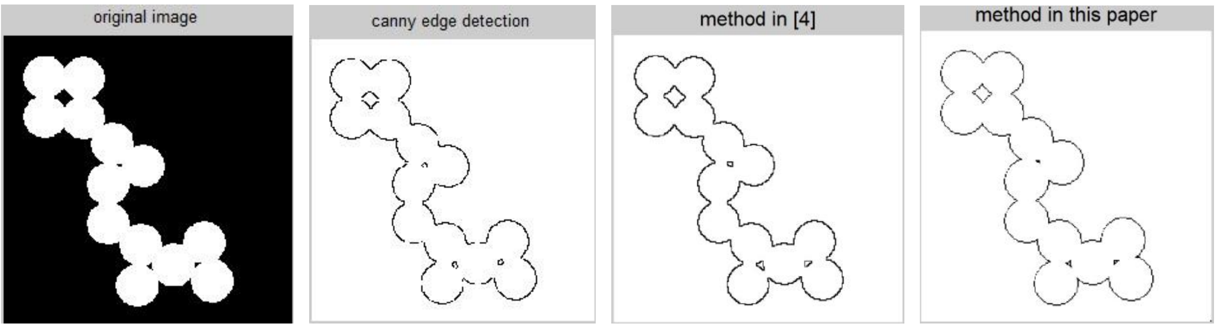

FIG.5. EDGE DETECTION OF CIRCLE IMAGE

From Fig.4 it can be seen that the edge images of this method are more accurate than classical canny operator and it has the same result with only use LMI method. But from Fig.5, it can be observed that edge detection of our method is thinner and more accurate than others and there is no discontinuity point in our edge detection picture.

Secondly, the gray image training sample, the same as binary edge detection which consists of an image and its corresponding desired edge image, is used to train CNN templates. The proposed method is compared with the method of [4] and [5].

The below are training templates of Fig.6.

$$A=\begin{bmatrix}0 & 0 & 0\\ 0 & 10.5171 & 0\\ 0 & 0 & 0\end{bmatrix}\quad B=\begin{bmatrix}-60.4543 & -173.1682 & -61.0564\\ -128.5413 & 876.4404 & -128.5413\\ -61.0564 & -173.1682 & -60.4543\end{bmatrix}\quad I=313.7354$$

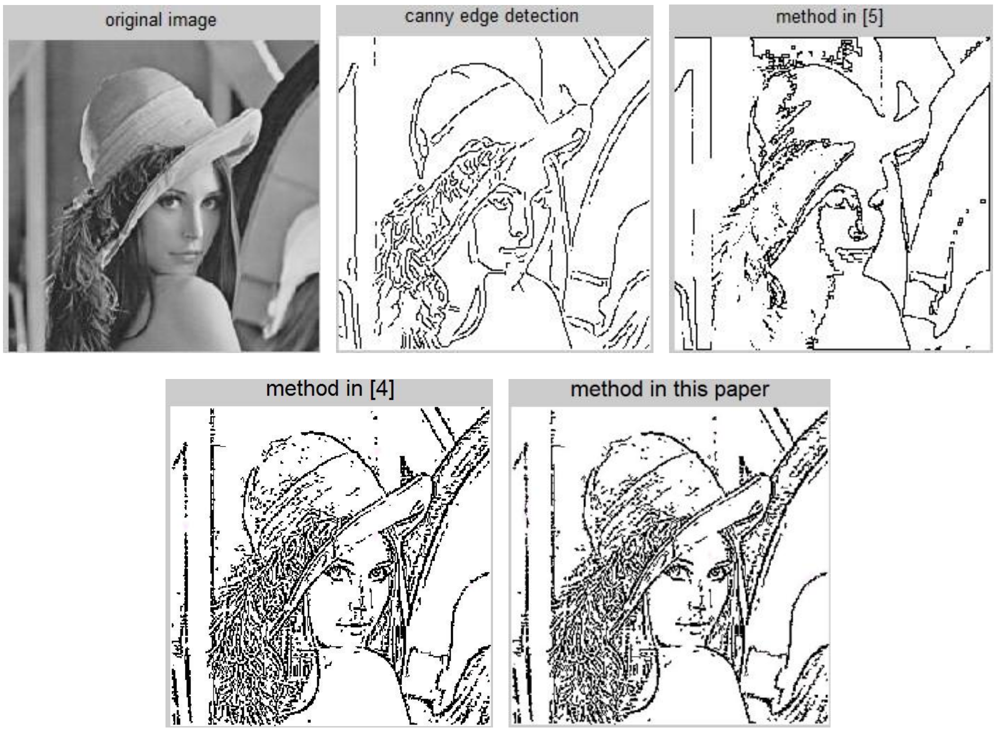

FIG.6. EDGE DETECTION OF LENNA IMAGE

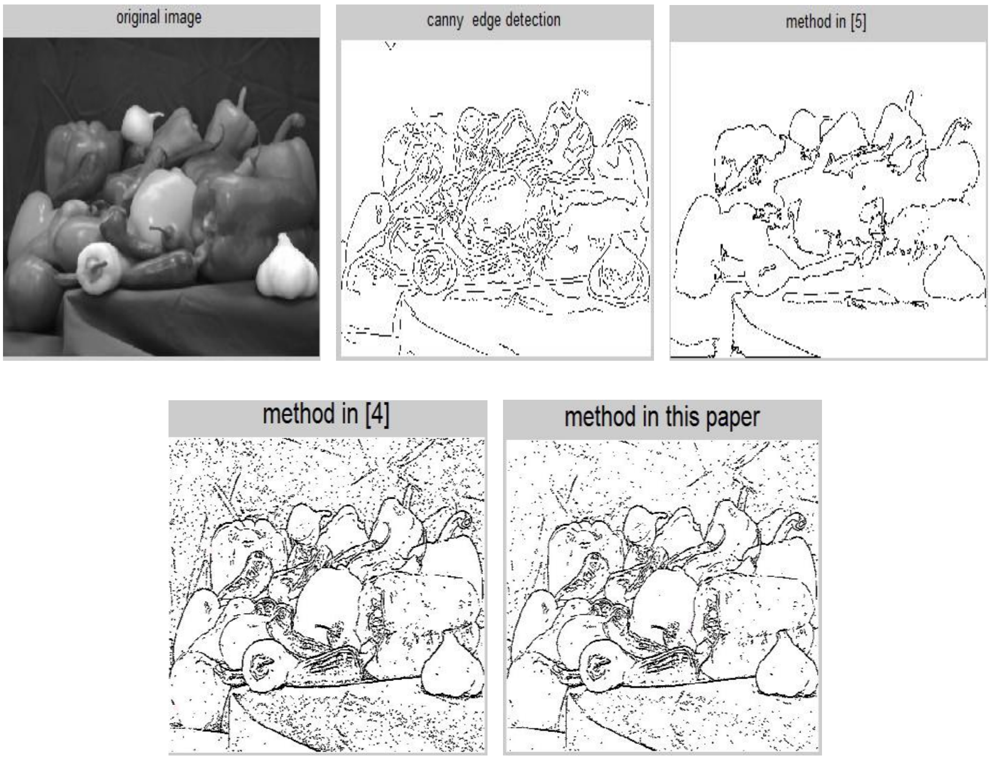

FIG.7. EDGE DETECTION OF VEGETABLES IMAGE

Fig.6 and 7 show that the edge images obtained by means of our proposed method are more accurate. The continuity of the lines is better than only use LMI method and there are less discrete dots in our obtained edge image. At the same time, edge detection lines of our method are thinner.

6. CONCLUSIONS

In this paper, the CNN templates are trained by a given training sample obtained from LMI and PSO. The CNN templates are employed to extract edge in binary and gray given images. Simulation experiment shows that the images after processed by suggested method is more accurate compared to typical operators.

From the Fig.6 and 7, it can be seen that there are many discrete dots in the images of our method as well as in the images of only use LMI method. These dots are caused by slight fluctuations in the images [12]. If we filter the images before edge detection, some details of the edge will be filtered. So how to preprocess the images before edge detection is necessary .

Images used for edge detection in this article are ideal images .But as known, images will introduce some noise during the transfer process. So when the images are noise images, we must do images noise cancellation before images edge detection, and this is also the focus of author's research in the further time.

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AUTHORS

[1]**Zhengxia Wang**, born in 1977, Rizhao City, Shandong Province. Associate Professor of Chongqing Jiaotong University, master tutor. The main research direction: the behavior of nonlinear dynamical systems, image processing.

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[2]**Lili Li**, graduate of Chongqing Jiaotong University. The main research direction: image processing.